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Valorification of volcanic tuff in constructions and materials manufacturing industry

Anca-Andreea Balog[a,]*, Nicoleta Cobîrzan[a], Claudiu Aciu[a], Dana Adriana Iluţiu-Varvara[a]

[a]*Technical University of Cluj-Napoca, 28 Memorandumului Street, 400114, Cluj-Napoca, Romania*

Abstract

Zeolitic volcanic tuffs are important local reserve, which can be exploited in building materials industry both as rocks and the preparation of mortar for masonry, lightweight concrete or autoclaved aerated concrete. This study presents the results of the tests performed on different mortar recipes that are based on zeolitic volcanic tuff (from Macicaş quarry situated in the north-western part of Cluj-Napoca area) used as a substitute for cement or aggregate. The aim of the study is to obtain new building material made from local resources that can be used to realize new masonry works and to rehabilitate the old ones.

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Keywords: local resources; volcanic tuff; building materials; mortar, microscopy.

1. Introduction

Used in the preparation of mortars and concrete, pozzolan materials are divided into two main categories: natural (volcanic ash, volcanic tuff, pumice, or burned clay) and artificial (silica fume, fly ash, blast furnace slag and so on). Volcanic tuff, one of the most important natural pozzolan materials, has been used since ancient times to prepare trass, but also to achieve rock masonry elements. Currently it is used in many countries in the world for masonry mortars, lightweight concretes and thermal for acoustic insulation materials.

* Corresponding author. Tel.: +40 075 4 015 409;
E-mail address: anca.balog@dst.utcluj.ro

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The industry of Portland cements generates about 7% of global CO_2 emissions [1], the main pollutant that leads to environmental pollution and global climate change.

Cenk Karakurt in 2010 said that *„the use of natural and artificial pozzolans as blend materials for cement has been constantly increasing in order to reduce energy consumption and CO_2 emission without causing any degradation to cement properties”* [2].

Depending on the mineralogical composition and physical-mechanical characteristics, zeolitic tuffs have uses in other areas: wastewater treatment, as lightweight aggregate for fertilizers in agriculture and horticulture, for theminimization of heavy elements in the soil, in animal husbandry, fisheries, for the separation of nitrogen from the air, elimination of radioactive elements (Cs and Sr) of nuclear waste, supplements in animal diets, deodorants [3].

The need to use organic materials to achieve new buildings materials to be compatible in rehabilitation of existing ones, led to the development of new materials that meet these criteria. Low operating cost, simple technologies or low embodied energy, are the benefits of using zeolitic tuffs in construction and building materials industry but also in other related fields.

2. Material and Method

Determinations were performed in order to identify the qualities and drawbacks of the recipes of mortars when zeolitic volcanic tuffs are used as raw materials in the building materials industry.

Volcanic tuff is a volcanic rock containing natural mineral zeolite (aluminium silicate alkaline) with a mainly vitreous structure. High reactive silica content determined by chemical analysis (Table 1) [4] gives Măcicaş quarry tuff pozzolanic character and hydraulic properties.

Table 1 Chemical analysis of volcanic tuff versus cement Portland

(%)	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	TiO_2
Macicaş volcanic tuff	5.46	63.98	14.53	1.71	0.23	1	0.88	-	0.35
Portland cement	60-67	17-25	3-8	0.5-6	0.1-4	0.2-1.3	-	1-3	-

Activation of natural pozzolanic materials occurs in the presence of hydrated lime or materials that can eliminate portlandite during hydration (e.g. Portland cement) and that lead to the formation of additional C-S-H, the main product of hydration.

$$\underset{(CalciumHydroxide)}{Ca(OH)_2} + \underset{(Silica)}{SiO_2} + \underset{(Water)}{H_2O} \rightarrow \underset{(Calcium\text{-}Silicate\text{-}Hydrate)}{C_3S_2H_3}$$

After Pone et all the: “*experiments conducted in China have revealed that a natural zeolite specimen composed of clinoptilolite mineral had a pozzolanic activity between silica fume and fly”*.[5]

The Macicaş volcanic tuff (from Cluj-Napoca County), has a high amount of zeolites content (clinoptilolite, phillipsite, heulandite, and mordenite, about 50-80%).

Considering the chemical contents of volcanic tuff from Macicas it has been establish puzzolanic characteristics and the possibility to substitute the cement Portland or aggregates in new mortar recipes.

In this respect, there have been prepared five new mortar recipes: in three of them tuff substitute the Portland cement and in others two recipes it substitute the aggregates (Table 2). Natural resin and artificial recycled sandstone were used in order to reduce the water/binding material ratio, while basalt scoria was used to improve mechanical properties of mortar samples.

Mortars were characterized from physical (bulk density, true density, apparent volume, water absorption) mechanical (bending and compressive strength) and mineralogical (in thin sections) point of view.

Table 2. Mortar recipes using tuff as substitute the cement and substitute the aggregates

Recipe	Binder [g/m^3]			W/B	Aditives [g]			Aggregate [g/m^3]	
	Cement II A-S 32,5R	Zeolitic tuff	Lime		Natural resin	Bazalt scoria	Artificial recycled sandstone	Zeolitic tuff	Sand
R1	225	225	-	0.68	-	-	-	-	1350
R2	225	225	-	0.66	13	-	-	-	1350
R3	225	225	-	0.62	-	45	-	-	1350
R4	-	-	500	1.00	-	-	150	1350	-
R5	500	-	-	1.33	-	-	150	1350	-

3. Results and Discussions

Bending strength was determined on three prismatic samples having 4x4x16cm according to SR EN1015-11/2002[6] while the compressive strength was determined on the halves prism resulted (Table 3). The values of compressive strength at 28 days, indicates the brand of the mortars [7].

Table 3. Physico-mechanical properties of mortars samples

Recipe	Apparent density [kg/m^3]	Bending strength f_{ti} [N/mm^2]	Compressive strength f_m [N/mm^2]	Mortar class
R1	2044	3.54	13.07	M 12.5
R2	2000	2.11	10.99	M10
R3	2103	3.76	14.26	M 12.5
R4	1804	4.04	16.92	M 15
R5	1390	1.17	4.06	M 2.5

According to P100/1-2006 [8] and CR6-2006 [9], the minimum compressive strength of masonry mortar is chosen depending on the type of construction (permanent or temporary). Thus R1 - R4 mortars fall in M10-M15 mortar classes with a compressive strength greater than 10 N/mm^2 and can be used both in the structural and in the non-structural walls regardless of type of construction, as opposed to the R5 mortar, which can be used only in special cases (e.g. the structural and non-structural elements of temporary buildings).

Water absorption was determined according to EN 1015-18/2003 [10] on prismatic specimens of 4x4x16 cm, and consisted in weighing the dried sample (m_0), gradual immersion in distilled water every 10 min (m_1), 90 min (m_2) and 24h (m_3) (Table 4); mortar class (depending on water absorption) was determined according to SR EN 998-2/2002 [11] and SR EN 998-1/2004 [12] (Table 4).

Table 4. Mortar classes according to water absorption

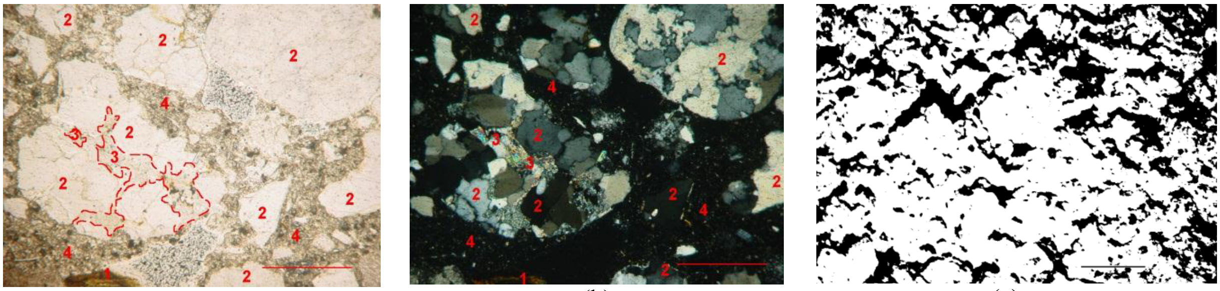
Recipe	Volume [cm^3]	m_0 [g]	m_1 (10 min) [g]	m_2 (90 min) [g]	Absorption coefficient [kg/(m^2 *min0.5)]	Class
R1	64	123.92	132.39	135.26	0.75	W0
R2	64	114.21	115.88	118.92	0.31	W1
R3	64	126.47	130.82	137.52	0.73	W0
R4	64	76.67	94.29	100.26	1.55	W0
R5	64	185.01	187.77	197	0.79	W2

Water absorption by capillarity of mortars has values in the range 0.31-1.55 kg/(m^2·min 0.5) which classifies analyzed mortars in classes W0, W1 or W2.

Adding volcanic tuff in cement improves workability, impermeability and the resistance of mortars to the sulphates attack.

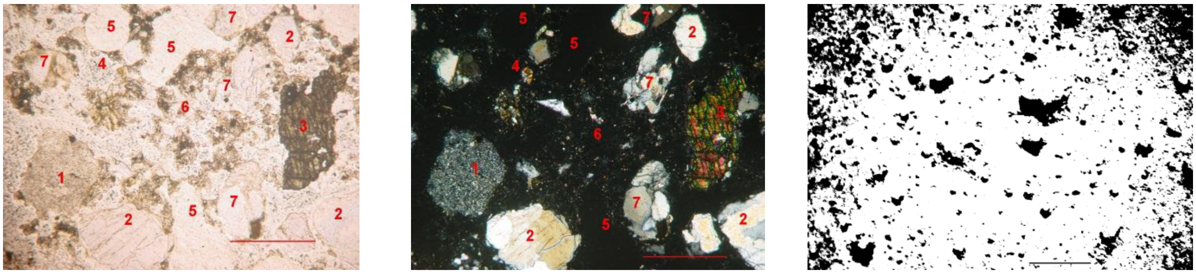
From a mineralogical standpoint, analysis were performed on thin sections at 28 days, using a polarized microscope (Jenapol) and apparent porosity was determined (on flat, polished of plaster surfaces) using a binocular microscope with transmitted light (Zeiss). Microscopical analysis on thin sections, enable the observation of mineralogical composition and alteration processes (zeolitizations, hydroxylation) (see Fig. 1,2,3,4,5- (a),(b)).

Based on microscopic observations, we can say that mortars are heterogeneous in terms of mineralogical composition, having volcanic glass, clay minerals, zeolites, crystals of quartz, feldspar (potassic, plagioclase), mica (muscovite and biotite), amphiboles and lithic fragments (mostly quartzite and shist) in their composition.



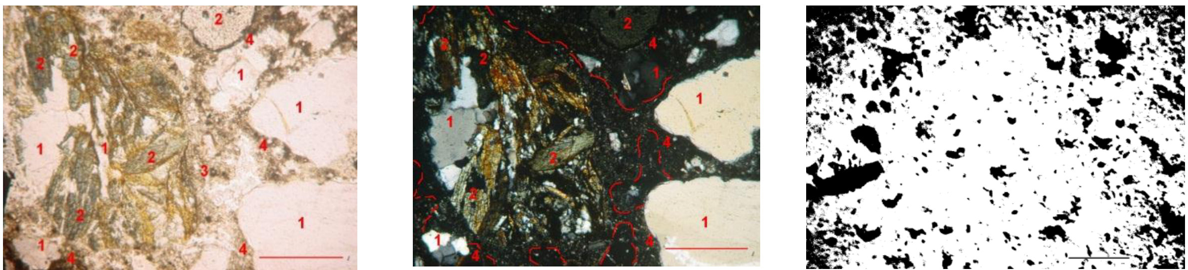
(a) (b) (c)

Fig. 1. Sample R1Thin section (a) at NII and (b) at N+ : 1-Biotite; 2-Quartz; 3-Mica in the quartzite fissures; 4-Izotrope minerals (maybe clay minerals); 5-fine groundmass (clay or carbonate); the scale bar represent 1 mm; (c) Polished surface of the mortar-photomicrographies made to the microscope, binary images; the scale bar is 1 mm



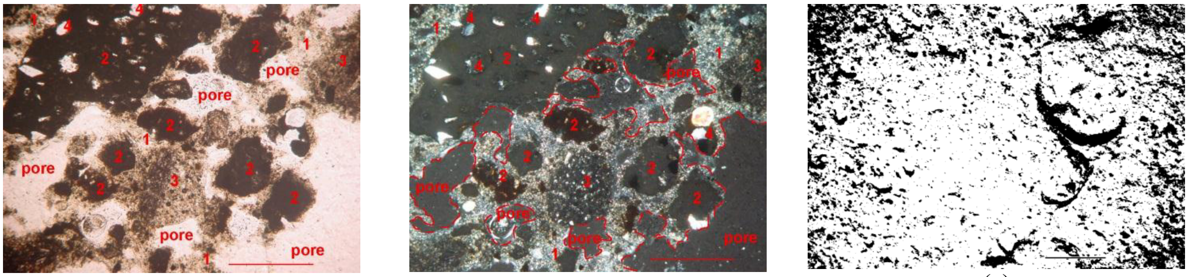
(a) (b) (c)

Fig. 2. Sample R2 Thin section (a) at NII and (b) at N+ : 1- Clasts; 2- Alterated Feldspar; 3- ?; 4-Biotite; 5-Pore; 6- Izotrope minerals (probably clay); 7-Quartz; the scale bar represent 1 mm; (c) Polished surface of the mortar-photomicrographies made to the microscope, binary images; the scale bar is 1 mm



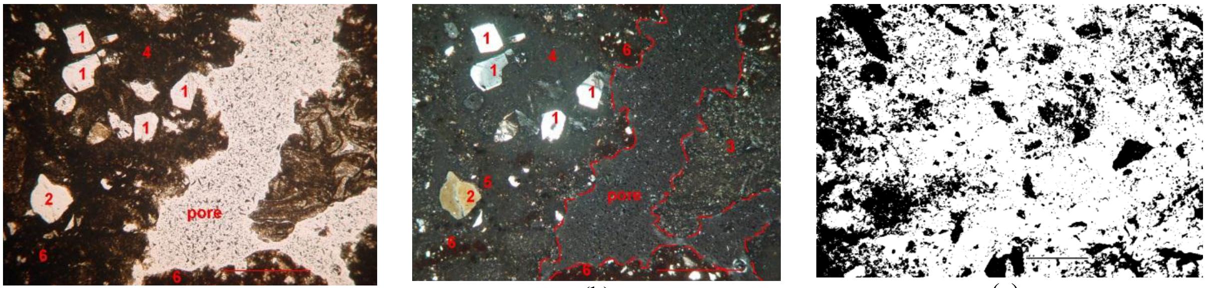
(a) (b) (c)

Fig. 3. Sample R3 Thin section (a) at NII and (b) at N+ : 1-Clasts of Quartz; 2-Biotite; 3-alteration around the gneiss clast; 4- alteration zone around the quartz; the scale bar represent 1 mm; (c) Polished surface of the mortar-photomicrographies made to the microscope, binary images; the scale bar is 1 mm



(a) (b) (c)

Fig. 4. Sample R4 Thin section (a) at NII and (b) at N+ : 1-Feldspar (from the tuff); 2-Opaque minerals ; 3-groundmass (clay); 4- Quartz; Pores; the scale bar represent 1 mm; (c) Polished surface of the mortar-photomicrographies made to the microscope, binary images; the scale bar is 1 mm



(a) (b) (c)

Fig. 5. Sample R5 Thin section (a) at NII and (b) at N+ : 1-Quartz; 2-Feldspars (zeolitizated and fissurated); 3- Groundmass (clay); 4- Izotrope minerals; 5-Alteration around the feldspars; the scale bar represent 1 mm; (c) Polished surface of the mortar-photomicrographies made to the microscope, binary images; the scale bar is 1 mm

The image analysis of porosity was performed on polished sections, on surfaces perpendicular to the direction of casting of mortars; the results are presented in Table 5. The percentage determination of the pores (Fig.1,2,3,4,5-(c)) was made with the ratio between the total numbers of black pixels to the total number of pixels.Thus we found that mortars based on tuff as a substitute to cement have porosities between 19.7% and 25.3% and those based on the aggregate tuff around 23.9 to 29.9%.

Table 5. Mortars apparent porosity

Recipe	Volume [cm^3]	Absorption coefficient [$kg/(m^2*min0.5)$]	Apparent porosity [%]
R1	64	0.75	25.3
R2	64	1.55	19.7
R3	64	0.73	24.2
R4	64	0.31	23.9
R5	64	0.73	29.9

The analysis of the samples showed the following differences between the mortars having tuff as binder (samples R1, R2, R3) and those based on aggregates (samples R4, R5):

- in first case the apparent density has the values between 2000 - 2103 kg/m^3, the compressive strength between 10.99 and 14.26 N/mm2 and tensile strength values in between 2.11 – 3.76 N/mm2; water absorption by capillarity has values in the range 0.31-0.75 kg/(m2·min0.5); and apparent porosity 19,7-25,3%;

- in second case the apparent density has the values between 1390 and 1804 kg/m3, the compressive strength 4.06 and 16.92 N/mm2 and tensile strength values 1.71 and 4.04 N/mm2; water absorption by capillarity has values in the range 0.80 and 1.55 kg/(m2·min0.5); and apparent porosity 23.3 and 29.9%.

Increasing the percentage of zeolite tuff in the groundmass, porosity and water absorption of mortars samples are increased due to the three-dimensional structure of zeolites. Additives as artificial recycled sandstone and natural resin were used in order to diminish the water/cement ratio, and porosity or water absorption.

Natural resin mortar (recipe R2) has lower apparent porosity and water absorption but an inferior mechanical strength to those of R1 or R3 mortars. Basaltic scoria mortar (recipe R3) has a higher apparent porosity than in the case of R2 recipe but lower than R1 sample and higher mechanical strength compared to R1 or R2 mortars.

Mortars based on artificial recycled sandstones (samples R4, R5) have waterproofing properties and may favor moisture evacuation from structural or non-structural masonry elements where this aspect became important (masonry works affected by weathering).

4. Conclusions

Tuff based mortars can be used both for the structural and thermal rehabilitation of existing buildings and for the new masonries work in case of low energy buildings. These are mortars with a higher porosity than Portland cement mortars, but with diminished embodied energy and low thermal conductivity coefficients.

Simple technologies of manufacturing (grinding, cutting, processing), low cost (120 euro/t), good mechanical properties compared to the other traditional building materials used in the present days on a large scale (lime-mortar, cement-mortar), are the most benefits of employing zeolitic tuffs in construction and building materials industry; their disadvantages is the high W/B ratio being necessary to correct it by incorporating the natural or artificial additives.

The zeolitized tuffs can be used in the manufacturing industry for producing blended cements, due to their pozzolanic properties.

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